NOTE ON A PHOTOGRAPHIC METHOD OF DETERMINING THE COMPLETE MOTION OF A GUN DURING RECOIL.

BY

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It is often desirable to have a permanent record of the paths described by the points of a moving body, which is changing its position so rapidly that the eye is unable to observe them; and where it is not practicable to interfere with the motion of the body by causing it to trace its own path mechanically upon some surface. This may be done by causing the light from the moving body itself to record its own path upon a photographic plate. The method has many advantages to recommend it, for example, the motion of the body itself is not interfered with, and the path may be easily reduced to any desired scale. It is usual in investigating the motion of rapidly vibrating phenomena, such as tuning forks, stretched strings, variable electric currents, etc., to employ a *moving* photographic plate; but to determine the path alone, the sensitive plate need have no motion but may remain at rest and be used in the ordinary way.

The details of experiment vary according to circumstances. An example will illustrate a method of experimenting. Suppose that the moving body is a wheel rolling upon a level rail, a model in the laboratory, and it is desired to record the motion of one point in its circumference. Place an ordinary camera at any convenient distance from the wheel perpendicular to its plane,

and focus sharply upon it. Attach to some point of the circumference of the wheel a luminous object such as a small incandescent lamp. This experiment requires that the room be dark, a condition easily obtained by working at night. First expose the camera, then roll the wheel carrying the small lamp across the field of view, then close the shutter. The exposure may be made in the dark room for any length of time without fogging the plate. Upon developing it will be found that the image of the lamp has described a minature cycloid upon the plate, an exact reproduction of the path described by the point of the wheel, and reduced in the ratio of the size of image to object.

Though the results obtained by experiments conducted upon the plan just indicated are perfectly satisfactory, giving good clear negatives with sharp curves distinctly traced upon them, as trials which we have made conclusively prove, yet in many cases the inconvenience of experimenting in a dark room is a great disadvantage.

Another plan involving the same principles but enabling the experimenter to work in strong sunlight is the following: Prepare a dead black screen of considerable area, sufficient to more than cover the complete motion to be recorded; attach it to the moving object, and to the center of the black screen fasten a bright bead. The brilliant element of the bead in strong sunlight, in contrast to the black screen which forms the background, will be sufficiently bright to describe a curve upon the plate. In this work sensitive plates are required and care must be taken that the exposure, before and after the motion has taken place, is as short as possible to avoid unnecessary fogging.

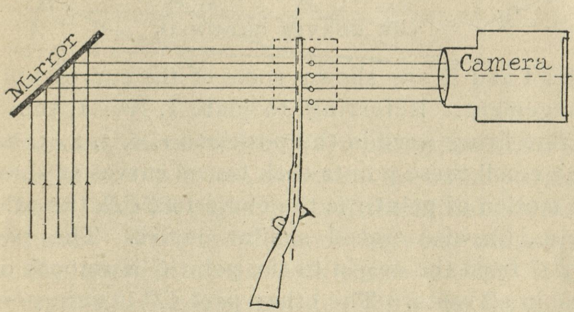
If instead of a single luminous point two or more such points are placed upon the moving object, the negative will show two or more curves, and from them the motion of the body may be completely determined, that is to say, its path through space may be so determined. There is however no accurate indication of the velocity which the moving body has at various points of its path. It should be said that the negatives do indicate roughly when the velocity is fast or slow, and when it is increasing or decreasing, by the intensities of the trace due to the relative times of exposure of each point. If by any means the source

of light upon the moving object could be made uniformly intermittent, such as the sparks from an electrical tuning fork for instance, then the record would not only give the path of the body but the velocity at each point of the path as well.

TO DETERMINE A RECOIL CURVE.

The above principles were applied to determine the behavior of a U. S. Army Springfield rifle during its recoil. The arrangement of apparatus is represented in figure 1.

Figure 1.



The rifle was fired from the shoulder as in ordinary practice. It is represented in the figure revolved through a right angle into the plane of the page to show the position of the luminous holes. Upon the muzzle of the gun is fastened a light piece of wood, which carries the black cardboard screen shown in outline in the figure. A piece of thin sheet copper fastened to the wood has a row of equidistant holes drilled through it, each being one millimeter in diameter with the distance between holes nineteen millimeters. The row of holes is approximately parallel to the axis of the gun. To obtain a brilliant illumination for the holes a mirror reflects sunlight through them to the camera. This method was adopted since more satisfactory results were obtained than with beads. The arrangement has its disadvantages since the size of the curve which can be recorded is practically limited by the size of the lens used in the camera: for should the gun move so far that the projection of a ray through a hole in the screen should fall outside of the lens, the illumination of the hole would not be sufficient to record itself. The

lens used in this experiment was over nine centimeters in diameter, being a Dallmeyer portrait lens 3*B* of their catalogue. This size was sufficient to cover the whole motion of this gun during recoil. A similar plan using a concave mirror instead of a plane one, would obviate the disadvantage mentioned above; namely, the necessity of having a large lens for the camera. In order to have the record of these curves the same size as the curves themselves, the lens was placed half way between the luminous holes and the camera plate. The distance of the lens from the holes was usually about two feet.

THE CURVES OBTAINED.

In plates I and II are shown some of the curves obtained by this arrangement. Referring to plate I, No. 1, the luminous points before firing were in the positions 1, 2, 3, 4, 5, and 6, and during the recoil these points each traced curves as shown. The complete motion of point 1 is the curve 1*ABCD*, the other points 2, 3, 4, etc., likewise traced similar curves. The part of the curve 1*ABC* from the origin to the point *C* is smooth and of the same type in all cases. The other part *CD* is unimportant and varies with the particular individual holding the gun. The exposure was made as short as possible after firing the gun to cut off this irregular part of the record. The point 1 is nearest the muzzle of the gun; the points 2, 3, 4, etc., are at equal intervals along a line parallel to the axis. It is seen from an examination of the curves that the first motion of the gun is very nearly straight to the rear for a distance of about 20 millimeters, shown by the parts of the curves corresponding to 1*A*. Here the point begins to rise rapidly, reaches its maximum at *B* and falls to *C*, where the recoil-proper ends.

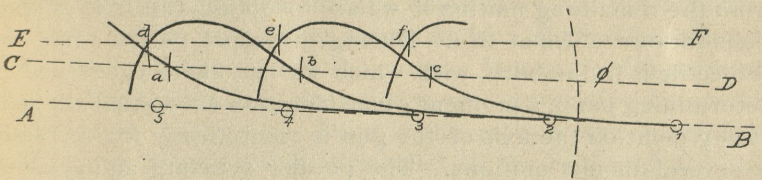
The intensity of the light at different points indicates the relative velocity which the gun had at these points of its path. During the first period when the gun moves straight to the rear, the curves are faint in each case, showing that the velocity was great; beyond this as the gun begins to rise, its velocity diminishes and the curves grow brighter, until at the summit *B* there is a maximum brilliancy. The great intensity of the irregular parts after recoil shows the comparatively slow velocity

which the gun has during this period. In plate I, No. 4, and plate II, Nos. 1 and 2, the light was accidently cut off before the latter part of the recoil path was completed but appeared again later as shown.

ANALYSIS OF THE CURVES.

Figure 2 represents actual curves taken with the Springfield rifle from which the instantaneous positions of the axis during

Figure 2.



its motion can be determined by a simple geometrical construction. The points 1, 2, 3, 4, etc., represent the initial positions of the luminous holes, and the right line *AB* the initial position of the axis of the gun. Since the distance between the holes remain invariable, the position of the axis corresponding to any point on any curve, as at *c*, is determined. With the assumed point *c* as a center, and a radius equal to the distance between consecutive holes on the diagram, describe the arc of a circle cutting the adjacent curve at the point *b*; and with *b* as a center using the same radius describe the arc cutting its adjacent curve at *a*, and so on for as many curves as are represented. These points of intersection must lie in a right line *CD* which represents the instantaneous position of the axis for the points considered. In like manner the points *d*, *e*, and *f* are determined by assuming one of them and constructing the other two, and the line *EF* represents another position of the gun's axis which shows an appreciable angular displacement, from the initial position *AB*, and indicates that the gun has at this instant a considerable angular velocity about an instantaneous axis at the intersection of *AB* and *EF*.

THE JUMP PROPER.

One of the problems of gunnery is the determination of what is technically called the angle of *jump*. The accuracy of modern high-power guns now requires that this angle should be known

to at least one minute of arc. The angle of jump may be defined to be the difference between the angle of elevation at which the gun is laid, and the angle of departure at which the projectile leaves the bore, and theoretically varies with each particular gun and mount as well as the angle of elevation itself; and should be determined by experiment in each case. The complete motion of a gun during recoil is theoretically complicated in its character, and the true angle of jump should be carefully differentiated from the remaining motion if we are to obtain the true corrections for our tables of fire. During the short period while the projectile is in the bore, with which we are alone concerned in determining jump, a moment's consideration shows that the path of any point on the axis of the gun is theoretically the resultant of several distinct motions. The powder pressure acting along the axis tends to produce a motion of translation of the gun and its upper carriage with respect to the chassis rails; while at the same time the gun tends to rotate about its trunnions, the gun and upper carriage about its rear part, and the whole mount about its base.

From the above considerations it is evident that if we could trace the consecutive positions of the axis of the gun between its initial position when the gun is laid before firing, continuously until it comes to rest, this moving axis would envelope a curve, the tangent to which at the instant the projectile leaves the bore would be the true angle of departure, and when known would determine the true angle of jump.

EXPERIMENTAL DETERMINATION OF JUMP.

An experiment was tried to determine the portion of these curves belonging to the jump proper, or how much of the curves are traced before the bullet leaves the gun. The method adopted was to attach behind one of the luminous holes a small piece of cardboard so that its edge came just to the edge of the hole without covering it. To this minute cardboard screen was attached a small copper wire seen at *WW*, plate II, No. 1. This wire was carried forward directly across the muzzle of the gun and fastened to a nail in the light board. When the bullet reached the muzzle the wire was struck by it and cut in two, but at the same time the tension on the wire was sufficient to draw

the cardboard forward and completely cover the hole. The curve should cease when this happens for this one hole only, while the curves of other holes are made complete. The cardboard passed completely by the hole and thus allowed the curve to begin again. The negative shows these points much better than the print can. The cardboard was originally at *A* attached to the wire *WW* leading across the muzzle. The curve appears again at *D* after the cardboard has passed completely by the hole. The portion of the curve described before the bullet arrives at the muzzle is so short that the only effect seems to be a slight elongation of the hole in the direction of the curve. It may be said therefore that a Springfield rifle does not move appreciably before the bullet leaves the muzzle. Even if the motion were appreciable its direction is such that it is parallel to the axis, and does not effect the aim of the gun. From this experiment the jump of a Springfield rifle is approximately zero, a result to be expected from practice with this gun.

In the case of large guns permanently mounted upon complicated carriages, the jump is often considerable, amounting to several minutes of arc and corresponding roughly to a muzzle motion of one or two inches, and its accurate determination is a matter of importance. On account of the comparatively large complete motions of recoil in such cases, a luminous object like an incandescent lamp upon the gun itself would seem a good method, and in order to remove the camera to such a distance as to be free from danger of the blast, it would only be necessary to employ a single plane mirror so placed as to reflect the rays into the camera placed at a safe distance in rear of the gun.

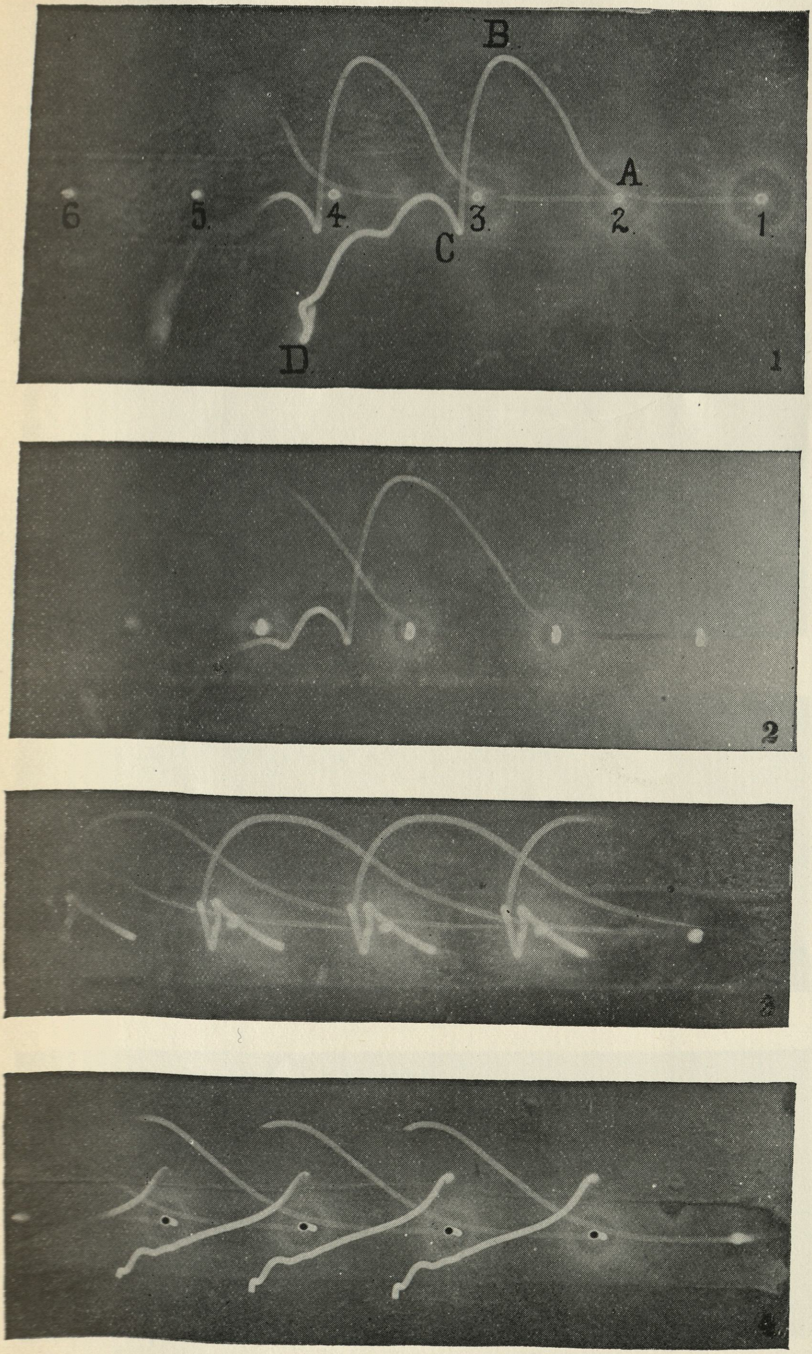


PLATE I.

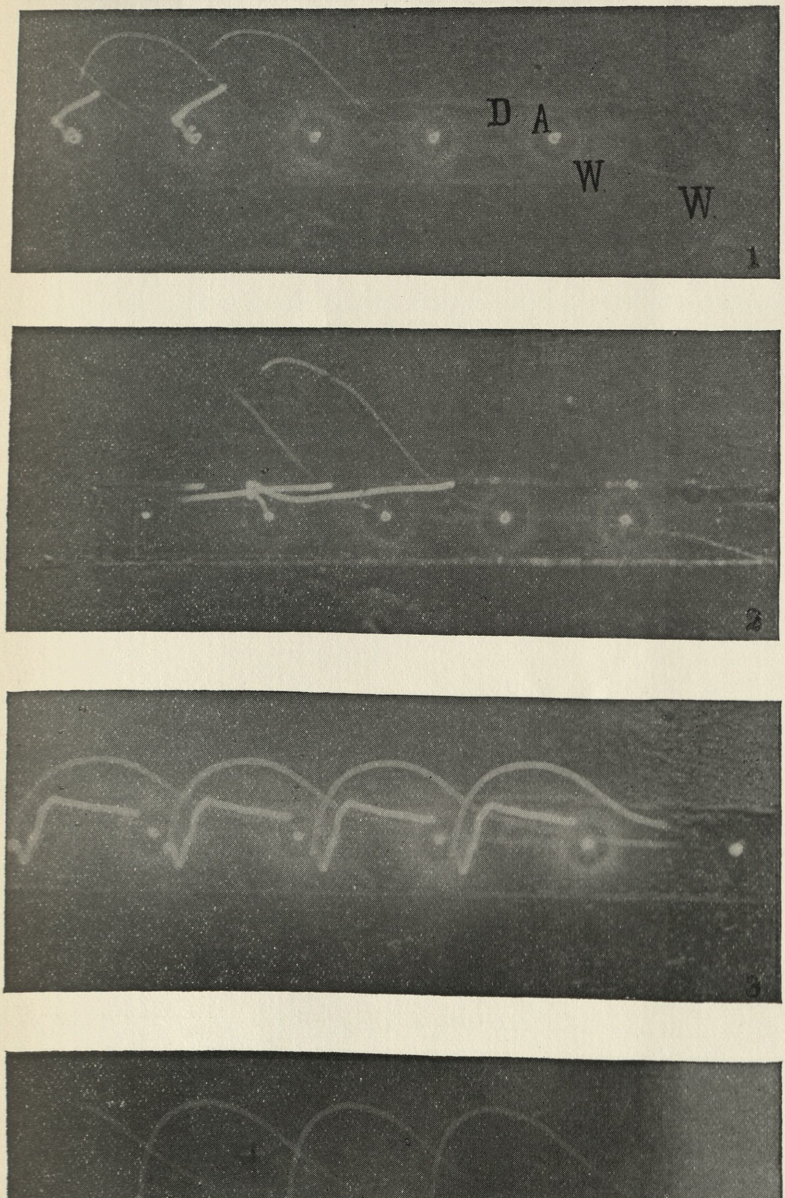


Plate II.